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RESEARCH PAPER

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Effects of hydrological variation on the aquatic plant community in a floodplain palustrine wetland of southern Brazil

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Abstract This study analyzed macrophyte richness, biomass, and composition under flooding of brief duration (less than 3 days) and drawdown events over an annual cycle in a floodplain palustrine wetland in the south of Brazil. The study was carried out to test the hypothesis that floods of brief and very brief duration are not long enough to compromise the richness and the biomass of aquatic macrophytes and that the alternation between wet and drawdown phases may cause variations in the macrophyte richness and composition. A total of 26 aquatic macrophyte species were observed from April 2003 to May 2004: 13 species were observed during the wet phase, and 24 during the drawdown phase. The mean richness was higher during the drawdown phase than during the wet phase, however, the mean biomass was similar in both phases. Although macrophyte richness was not modified after the three flooding events, mean biomass was modified after two events. The number of macrophyte species of which the biomass was modified after the first flooding event increased with subsequent floods. These results illustrate the importance of the dynamics between brief floods and drawdown events to the aquatic plant community in floodplain wetlands in southern Brazil.

Key words Drawdown · Flood · Macrophyte · Neotropical region · Wetland

Introduction

Floodplains are characterized by hydrological fluctuations, and the alternation of terrestrial and aquatic phases contributes to a high biodiversity (Gopal and Junk 2000). The degree of tolerance of species to hydrological extremes (floods and drawdown events) determines the structure of macrophyte communities (van Geest et al. 2005a, b).

In floodplain habitats, several surveys have analyzed the importance of flooding events in the maintenance of macrophyte richness and succession (van den Brink et al. 1991; van Geest et al. 2005a). The duration of flooding is an important agent of biological stability in wetland systems (Turner and Dale 1998). Casanova and Brock (2000) analyzed how water depth and duration and frequency of flooding influenced the establishment of the wetland plant community. According to them, flooding compromised the penetration of light and the ability of emergent plants to reach the surface by increasing the water depth (Casanova and Brock 2000). However, many studies in large river–floodplain systems analyzed the effects of long-duration flooding on macrophyte richness and composition (Junk 1989; Ferreira 2000). Studies that analyze the effects of floods of brief duration (less than 3 days) and low water depth in wetland systems are important because they give insight on how aquatic plants respond to disturbance by floods of different magnitudes.

The drawdown is also an important determinant of composition and abundance of aquatic plants (Wilcox and Meeker 1991). The drawdown is the sediment exposure when surface water has evaporated or has otherwise been removed. Drawdown events can have catastrophic effects on aquatic vegetation, decreasing the aboveground biomass of most species (Richardson et al. 2002). Van Geest et al. (2005a) noticed in lakes repeatedly disturbed by drawdown events that the macrophyte composition was basically composed of desiccation-tolerant species.

This study analyzed macrophyte richness, biomass, and composition under flooding of brief duration (less than 3 days) and drawdown events over an annual cycle (2003–2004) in a floodplain palustrine wetland in the south of Brazil. The study was carried out to test the hypothesis that floods of brief and very brief duration are not long enough to compromise the richness and the biomass of aquatic macrophytes and that the alternation between wet and drawdown phases may cause variations in macrophyte richness and composition.

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Materials and methods

Study area

The study was carried out in a floodplain palustrine wetland located in the south of Brazil (Novo Hamburgo, Rio Grande do Sul; 29°43′19.7″ S, 51°01′26.0″ W) (Fig. 1). The floodplain system is associated with the Guari Stream, a third-order permanent tributary of the lower course of the Sinos River. The Guari Stream is approximately 11 km long and 3 m wide, from its origin 100 m above sea level to its confluence with the Lomba Grande wetland, 3 m above sea level. Annual precipitation in the Sinos River basin (approximately 4000 km^2) ranges from 1200 to 2000 mm year^{-1} and is well distributed throughout the year. Increases in discharge resulting from high precipitation generate a series of floods of brief and very brief duration that temporarily inundate the studied floodplain.

The study area comprised 2 ha of a wetland class (palustrine wetland) representative of the Sinos River basin and was located between the lower course of the Guari Stream and a shallow lake of about 4 ha, 500 m away from the Guari stream (see Fig. 1). The hydric soil of the palustrine wetland was constituted basically of silt.

Sampling and statistical analyses

Macrophytes were collected from April 2003 to May 2004. The mean biomass and the richness were measured through the quadrat method (Downing and Anderson 1985). Eight quadrats (30 × 30 cm) were sampled at random in the palustrine wetland. All the living aboveground macrophytes inside the quadrat were removed. Plant material was washed to remove periphyton and deposited organic and inorganic materials. Washed plants were separated by species and dried in an oven at 60°C until reaching a constant weight (about 72 h). The macrophyte biomass of each quadrat was expressed in grams of dry weight per square meter (gDW m^{-2}), and the macrophyte richness corresponded to the number of species in each quadrat. During each collection, the water depth was measured with a graduated staff. The duration of flooding was measured in days, and the flooding was classified as brief (2–7 days duration) and very brief (4–48 h duration) (Tiner 1999).

To examine resistance to flooding, variations in macrophyte biomass and richness before and after floods were compared. Resistance of macrophytes was estimated for each flood event by comparing biomass and richness before and after each flood using a t test (SYSTAT 2000). If these differences were not significant ($P > 0.1$), the macrophyte community was considered resistant to floods (Maltchik et al. 2004). No collections were performed during the flooding events. Macrophyte richness and biomass after the flooding events were recorded only when the exchange of surface water between Guari Stream and the floodplain system under study had finished.

The mean biomass and richness of macrophytes between wet and drawdown phases were compared using a t test (SYSTAT 2000). Macrophyte frequency and dominance were calculated based on the presence and biomass during each hydrological phase. The tolerance of each macrophyte species to water-level variation was tested using the t test based on mean biomass values and mean dominance in both hydrological phases (SYSTAT 2000).

The composition of macrophytes during the study period was analyzed using detrended correspondence analysis (DCA). Change of macrophyte composition between the two hydrological phases was tested by multi-response permutation procedures (MRPP). Then, we carried out the indicator species analysis (Dufrene and Legendre 1997), tested through a Monte Carlo test (5000 iterations). All analyses were performed with PC-ord (McCune and Mefford 1997).

Results and discussion

The study period was divided into two hydrological phases: wet phase (with occurrence of flood events and presence of

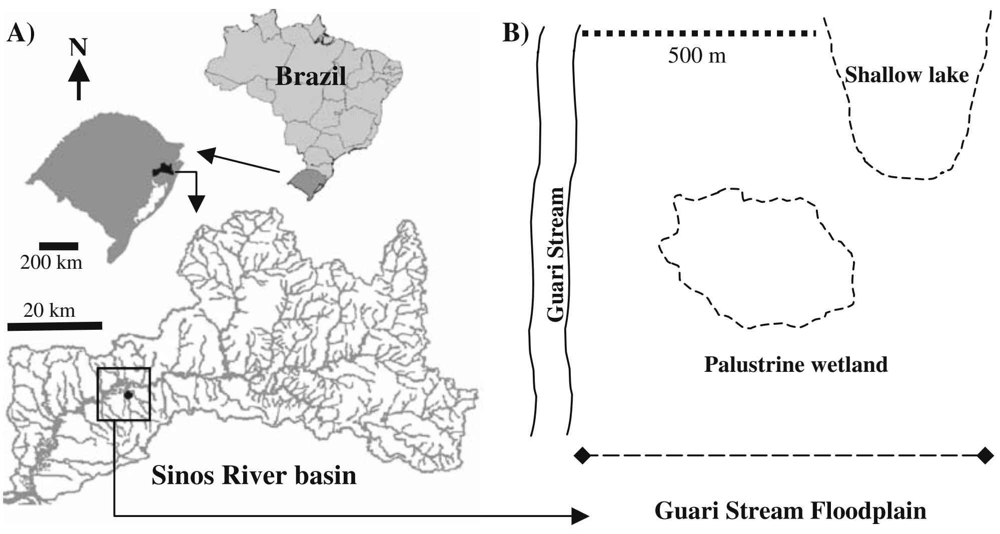

Fig. 1. Location of the floodplain palustrine wetland in the State of Rio Grande do Sul (Brazil): map (**A**); sketch (**B**)

surface water; from April 16 to July 9), and drawdown phase (lack of surface water but presence of saturated soil; from August 6 to May 7) (Table 1). The wet phase had three flooding events. Two floods were classified as being of very brief duration (1 day), and one flood was classified as brief duration (3 days) (Table 1). The maximum water depth in the wet phase was approximately 40 cm, reached during the flooding events.

A total of 26 aquatic macrophyte species were observed during the study period: 13 species were observed during the wet phase and 24 during the drawdown phase. The mean richness was higher in the drawdown phase than in the wet phase ($t = -2.541$; $df = 12$; $P = 0.026$), and the mean biomass was similar in both hydrological phases ($t = -0.415$; $df = 12$; $P = 0.685$). Macrophyte richness was not modified after the three flood events; however, the mean biomass was modified after two events (June and July) (Table 2). The number of macrophyte species with modified biomass after the flooding events increased with the recurrence of these events. Although modification of biomass did not occur in any species after the first flood, the biomass of 1 species [*Eichhornia crassipes* (Mart.) Solms] and 3 species of macrophytes [*Myriophyllum aquaticum* (Vell.) Verdc., *E. crassipes*, and *Eleocharis interstincta* (Vahl) Roem. & Schult.] were modified after the second and the third flood, respectively (Table 3).

A total of four macrophyte species (*Eichhornia crassipes*, *Enydra anagallis* Gardner, *Luziola peruviana* Juss. ex J. F. Gmel., and *Myriophyllum aquaticum)* were observed in all collections. However, ten macrophyte species were observed in just one collection during the study period: two in the wet phase (*Salvinia minima* Backer and *Paspalidium* sp.) and eight in the drawdown phase (*Scirpus cubensis* Poepp. & Kunth, *Lilaeopsis attenuata* (Hook. & Arn.) Fernald, *Leersia hexandra* Sw., *Cyperus lanceolatus* Poir., *Fimbristylis autumnalis* (L.) Roem. & Schult., *Rhynchospora aurea* Vahl, *Centella asiatica* (L.) Urb., and *Cyperus ferax* Rich.).

Luziola peruviana, *Eichhornia crassipes*, *Enydra anagallis*, *Myriophyllum aquaticum*, and *Eichhornia azurea* (Sw.) Kunth were representative of 91% of the total macrophyte biomass over the year and almost 96% of the total biomass in the wet phase. *L. peruviana*, *E. crassipes*, *E. anagallis*, and *M. aquaticum* represented 88.3% of the total macrophyte biomass in the drawdown phase. The mean biomass of *L. peruviana* was higher in the drawdown phase than in the wet phase ($P < 0.05$). Although *E. azurea* reached its biomass peak and had higher dominance values in the wet phase, *E. interstincta* reached higher values of biomass and dominance in the drawdown phase ($P < 0.05$).

Based on the DCA ordination, the first and the second axes of DCA explained 52.9% of the variance in the macrophyte composition (38.4% and 14.5%, respectively) (Fig. 2). Although *E. azurea*, *S. minima*, *Eleocharis elegans* (Kunth) Roem. & Schult., and *M. aquaticum* were more associated with the wet phase, *C. lanceolatus*, *F. autumnalis*, *Eleocharis acutangula* (Roxb.) Schult., and *Paspalum paniculatum* (L.) Kuntze were more associated with the drawdown phase (Fig. 2). Regarding the macrophyte composition, the sample scores (axis 1 and axis 2) separated the phases with and with-

Table 1. Physical characteristics of the study floodplain palustrine wetland (2003–2004)

	Apr/16	Apr/25	Apr/30	May/28	Jun/16	Jun/18	Jul/7	Jul/9	Aug/6	Aug/20	Sep/3	Oct/1	Oct/29	Dec/10	Feb/20	Mar/12	May/7
Phases	Wet								Drawdown								
Flood duration (days)	–	1	–	–	1	–	3	–	–	–	–	–	–	–	–	–	–
Days after flooding (days)	–	–	5	33	–	2	–	0	28	42	56	84	112	154	226	247	303
Water depth (cm) (±SD)	3.6 (4.2)	40	24 (9.6)	24 (6.5)	40	39 (13.4)	40	30 (4.1)	–	–	–	–	–	–	–	–	–
Total richness	7	–	8	7	–	8	–	9	9	7	7	8	13	11	11	12	10
Mean richness (±SE)	3.25 (0.25)	–	3.75 (0.25)	3.5 (0.42)	–	4 (0.38)	–	4 (0.27)	4.13 (0.35)	3.63 (0.32)	3.88 (0.38)	4.5 (0.38)	5.5 (0.46)	5.75 (0.37)	5.38 (0.42)	4.75 (0.79)	4.13 (0.58)
Mean biomass (±SE)	276.5 (53.5)	–	293.1 (56.3)	172.7 (20.5)	–	87.7 (8.5)	–	147.1 (21.6)	153.3 (22.9)	155.3 (12.1)	218.7 (31.2)	344.8 (36.2)	313.5 (34.1)	161.9 (22.5)	232.5 (33.8)	195.1 (19.9)	146.2 (18.4)

SD, standard deviation; SE, standard error

Table 2. Resistance (percent change in biomass and richness) of the macrophyte community in a floodplain palustrine wetland in southern Brazil

Date	Flood duration (days)	Biomass change (%)	Richness change (%)
April 25	1	6.01 ($P = 0.833$)	15.38 ($P = 0.179$)
June 16	1	–49.23 ($P = 0.002$)	14.28 ($P = 0.393$)
July 7	3	67.71 ($P = 0.023$)	0 ($P = 1.000$)

Table 3. Resistance (percent change in biomass) of macrophyte species after flooding events in a floodplain palustrine wetland in southern Brazil

Date	Biomass change (%)		
Flood duration	April 25 1 day	June 16 1 day	July 7 3 day
Eichhornia azurea (Sw.) Kunth	–34.02 ($P = 0.511$)	–94.15 ($P = 0.117$)	2571.3 ($P = 0.168$)
Eichhornia crassipes (Mart.) Solms	24.54 ($P = 0.75$)	–53.52 ($P = 0.058$)	–97.78 ($P = 0.009$)
Enydra anagallis Gardner	–99.59 ($P = 0.262$)	–49.77 ($P = 0.639$)	1825.93 ($P = 0.11$)
Ludwigia grandiflora (Michx.) Greuter & Burdet	–100 ($P = 0.264$)	–	–
Luziola peruviana Juss. ex J.F. Gmel.	5.09 ($P = 0.772$)	28.58 ($P = 0.133$)	–22.86 ($P = 0.429$)
Myriophyllum aquaticum (Vell.) Verdc.	2038.02 ($P = 0.284$)	13.9 ($P = 0.845$)	218.5 ($P = 0.084$)
Alternanthera philoxeroides (Mart.) Griseb.	291.67 ($P = 0.482$)	–	–100 ($P = 0.150$)
Eleocharis interstincta (Vahl) Roem. & Schult.	–	–70.45 ($P = 0.377$)	–100 ($P = 0.069$)
Hydrocotyle ranunculoides L. f.	–	–100 ($P = 0.334$)	–
Heteranthera limosa (Sw.) Willd.	–	–	–100 ($P = 0.149$)

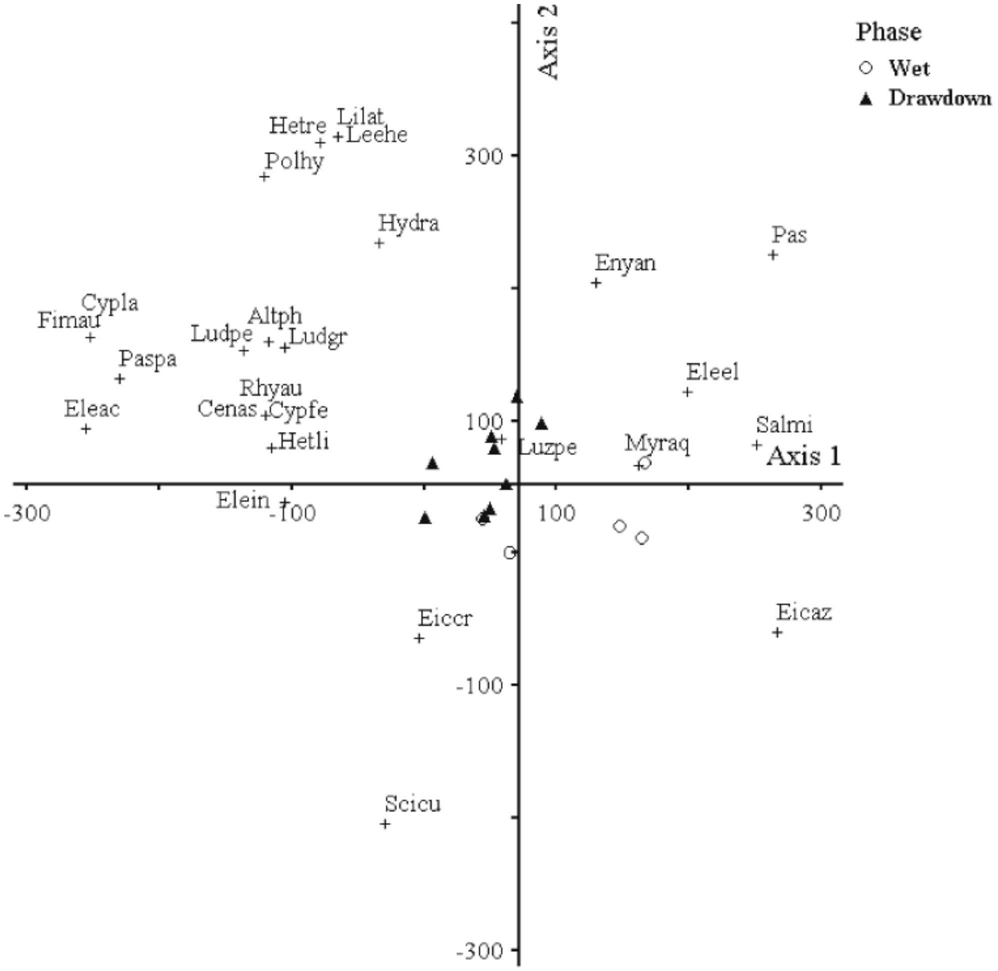

Fig. 2. Detrended correspondence analysis (DCA) of the composition of aquatic macrophytes in the subject floodplain palustrine wetland. *Altph*, *Alternanthera philoxeroides* (Mart.) Griseb.; *Cenas*, *Centella asiatica* (L.) Urb.; *Cypfe*, *Cyperus ferax* Rich.; *Cypla*, *Cyperus lanceolatus* Poir.; *Eicaz*, *Eichhornia azurea* (Sw.) Kunth; *Eiccr*, *Eichhornia crassipes* (Mart.) Solms; *Eleac*, *Eleocharis acutangula* (Roxb.) Schult.; *Eleel*, *Eleocharis elegans* (Kunth) Roem. & Schult.; *Elein*, *Eleocharis interstincta* (Vahl) Roem. & Schult.; *Enyan*, *Enydra anagallis* Gardner; *Fimau*, *Fimbristylis autumnalis* (L.) Roem. & Schult.; *Hetli*, *Heteranthera limosa* (Sw.) Willd.; *Hetre*, *Heteranthera reniformis* Ruiz & Pav.; *Hydra*, *Hydrocotyle ranunculoides* L. f.; *Leehe*, *Leersia hexandra* Sw.; *Lilat*, *Lilaeopsis attenuata* (Hook. & Arn.) Fernald; *Ludgr*, *Ludwigia grandiflora* (Michx.) Greuter & Burdet; *Ludpe*, *Ludwigia peploides* (Kunth) P.H. Raven; *Luzpe*, *Luziola peruviana* Juss. ex J.F. Gmel; *Myraq*, *Myriophyllum aquaticum* (Vell.) Verdc.; *Pas*, *Paspalidium* sp.; *Paspa*, *Paspalum paniculatum* (L.) Kuntze; *Polhy*, *Polygonum hydropiperoides* Michx.; *Rhyau*, *Rhynchospora aurea* Vahl; *Salmi*, *Salvinia minima* Baker; *Scicu*, *Scirpus cubensis* Poepp. & Kunth

out floods (axis 1, $t = 3.066$; $df = 12$; $P = 0.01$; axis 2, $t = -2.390$; $df = 12$; $P = 0.034$). *E. azurea* (Indicator Value (IV) = 99.9; $P = 0.001$) was typical of the wet phase, whereas *L. peruviana* and *E. interstincta* characterized the drawdown phase (IV = 60.7, $P = 0.035$; IV = 87.6, $P = 0.002$, respectively).

Macrophyte richness and biomass are driven by flood attributes, such as duration and frequency (Robertson et al. 2001; Maltchik et al. 2004, 2005; van Geest et al. 2005b). Casanova and Brock (2000) observed that the frequency and duration of the floods were important attributes influencing plant communities when water levels fluctuate. In the palustrine wetland we studied, macrophyte richness was not modified after every flooding event, indicating that floods of brief or very brief duration (less than 3 days) do not necessarily change macrophyte richness. However, the number of macrophyte species that had modified biomass after the first flooding event increased with subsequent floods. This result indicated that successive floods of brief duration can decrease the resistance of some species of macrophytes. The resistance of *M. aquaticum*, *E. crassipes*, and *E. interstincta* was decreased with the recurrence of the floods. The nature of the damage of these three species was not analyzed because our study only compared macrophyte richness and biomass before and after flooding events. However, it is likely that the nature of the damage was mostly mechanical, because the water depth reached during flooding was low (maximum water depth, approximately 40 cm), and such depths are unlikely to affect the penetration of solar radiation and thus limit the ability of aquatic plants to reach the water surface.

The water-level variation can affect the establishment, growth, and survival of aquatic plants (Blanch et al. 1999; Seabloom et al. 2001). The variation in wetland vegetation is driven by changes in aquatic macrophyte populations whose response to hydrological oscillation can occur in several ways (van der Valk 2005). In the wetland studied, the water-level oscillation was held responsible for a difference in the richness and composition of aquatic macrophytes, although the biomass was similar during both hydrological phases. The greatest richness of species during the drawdown phase was caused by the establishment of 13 new macrophyte species and the persistence of 11 already existing species throughout the wet phase. Soil exposition may allow for seed bank germination (Smith and Kadlec 1983). The settlement of new species and the macrophyte resistance to soil exposure led to a composition change and an increase in macrophyte richness in the system. The occurrence of very small individuals of *F. autumnalis* and *C. ferax* in the drawdown phase is an indication of recruitment of these species.

According to Neiff (1975), although the peak of biomass of some macrophyte species occurs during the flooding period, other species show high biomass values at low water level. During this study, although *E. azurea* biomass was higher in the wet phase, the mean biomass of *L. peruviana* and *E. interstincta* was greater in the drawdown phase. These variations in the biomass peaks of *E. azurea* and *L. peruviana* maintained a similar mean biomass of macrophytes during both hydrological phases.

Van der Valk (2005) suggested that the range of hydrological oscillation during wet–dry phases determines the nature of change occurring in an aquatic plant community. Small hydrological variations (less than 50 cm in depth) may lead to changes in species dominance. On the other hand, greater hydrological variations (more than 150 cm in depth) would allow for a change in the species composition (van der Valk 2005). Throughout the study period, the maximum variation in water level was 40 cm. In this study, we observed that the small hydrological variation was sufficient to modify macrophyte biomass and composition and, for some species, dominance.

Our results confirmed our initial hypothesis that flooding events of brief and very brief duration do not influence the richness of the macrophyte species, although they have changed macrophyte biomass. We believe that the recurrence of flooding events could have decreased the resistance to disturbance by floods of some species. The hydrological variation (wet and drawdown phases) changed the composition of macrophyte species and increased their richness in the studied wetland. Such results emphasize the importance of brief floods and drawdown events for the aquatic plant community in floodplain wetlands in southern Brazil.

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References

Blanch SJ, Ganf GG, Walker KF (1999) Tolerance of riverine plants to flooding and exposure by water regime. Regul Rivers Res Manag 15:43–62

Casanova MT, Brock MA (2000) How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? Plant Ecol 147:237–250

Downing JA, Anderson MR (1985) Estimating the standing biomass of aquatic macrophytes. Can J Fish Aquat Sci 42:1860–1869

Dufrene M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Monogr 67:345–366

Ferreira LV (2000) Effects of flooding duration on species richness, floristic composition and forest structure in river margin habitat in Amazonian blackwater floodplain forests: implications for future design of protected areas. Biodivers Conserv 9:1–14

Gopal B, Junk WJ (2000) Biodiversity in wetlands: an introduction. In: Gopal B, Junk WJ, Davies JA (eds) Biodiversity in wetlands: assessment, function and conservation. Backhuys, Leiden, pp 1–10

Junk WJ (1989) Flood tolerance and tree distribution in central Amazonia. In: Holm-Nielsen LB, Nielsen IC, Balslev H (eds) Tropical forest botanical dynamics, speciation and diversity. Academic Press, London, pp 47–64

Maltchik L, Rolon AS, Groth C (2004) The effects of flood pulse on the macrophyte community in a shallow lake of Southern Brazil. Acta Limnol Bras 16:103–113

Maltchik L, Oliveira GR, Rolon AS, Stenert C (2005) Diversity and stability of aquatic macrophyte community in three shallow lakes associated to a floodplain system in the south of Brazil. Interciencia 30:166–170

McCune B, Mefford MJ (1997) PC-ord – multivariate analysis of ecological data, version 3.0. MJM Software, Gleneden Beach, OR

Neiff JJ (1975) Annual fluctuations in composition and biomass of macrophytes in the marginal lagoons of mid-Paraná River (in Spanish). Ecosur 2:153–183

Richardson SM, Hanson JM, Locke A (2002) Effects of impoundment and water-level fluctuations on macrophyte and macroinvertebrate communities of a dammed tidal river. Aquat Ecol 36:493–510

Robertson AI, Bacon P, Heagney G (2001) The responses of floodplain primary production to flood frequency and timing. J Appl Ecol 38:126–136

Seabloom EW, Maloney KA, van der Valk AG (2001) Constraints on the establishment of plants along a fluctuating water-depth gradient. Ecology 82:2216–2232

Smith LM, Kadlec JA (1983) Seed banks and their role during drawdown of a North American marsh. J Appl Ecol 20:673–684

SYSTAT (2000) Systat Version 10 for Windows. SPSS Inc., Chicago

Tiner RW (1999) Wetland indicators: a guide to wetland identification, delineation, classification and mapping. Lewis, New York

Turner MG, Dale VH (1998) Comparing large, infrequent disturbances: what have we learned? Ecosystems 1:493–496

van den Brink FWB, Maenen MMJ, van der Veld G, Bij de Vaate A (1991) The (semi-) aquatic vegetation of still waters within the floodplains of the rivers Rhine and Meuse in the Netherlands: historical changes and the role of inundation. Verh Int Ver Limnol 24: 2693–2699

van der Valk AG (2005) Water-level fluctuations in North American prairie wetlands. Hydrobiologia 539:171–188

van Geest GJ, Coops H, Roijackers RMM, Buijse AD, Scheffer M (2005a) Succession of aquatic vegetation driven by reduced water-level fluctuations in floodplain lakes. J Appl Ecol 42:251–260

van Geest GJ, Wolters H, Roosen FCJM, Coops H, Roijackers RMM, Buijse AD, Scheffer M (2005b) Water-level fluctuations affect macrophyte richness in floodplain lakes. Hydrobiologia 539:239–248

Wilcox DA, Meeker JE (1991) Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. Can J Bot 69:1542–1551